Pfisterer & Berolzheimer

The Cost of Power in Illinois

Mechanical Engineering

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THE COST OF POWER IN ILLINOIS

BY

George Edward Pfisterer
Solomon Milton Berolzheimer

THESIS FOR THE DEGREE OF BACHELOR OF SCIENCE
IN MECHANICAL ENGINEERING

IN THE
COLLEGE OF ENGINEERING
OF THE
UNIVERSITY OF ILLINOIS
PRESENTED JUNE, 1908

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UNIVERSITY OF ILLINOIS

June 1, 1908

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

GEORGE EDWARD PFISTERER SOLOMON MILTON BEROLZHEIMER

ENTITLED THE COST OF POWER IN ILLINOIS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Mechanical Engineering

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THESIS.

COST OF POWER IN ILLINOIS.

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COST OF POWER IN ILLINOIS.

In the consideration of the cost of Power in any State of the Union, it would be well to consider the resources of that state and to study their effect on this power cost. With this fact in view we shall consider the many and varied industries of Illinois. In this state 11,622 miles of railway were in operation on June 30, 1904, which afforded abundant transportation facilities for all parts. With the Mississippi forming its western boundary, the Ohio its southern, and with Lake Michigan on the north affording deep water communication with the world, Illinois has excellent water transportation facilities. The state is rich in natural resources, its coal fields being the most extensive of any of the states. Agriculture and Manufactures are leading industries and rank second and third respectively in the list of States. In 1902 the state ranked sixth in mining; in 1906, third in population and fifth in amount of steam power used in manufactures.

The natural resources of the state are unusually large, coal being the principal and largest mineral product, while agriculture is the most prominent natural one. However, the coal fields will interest us most extending as they do for 275 miles in a north and south direction and 225 miles from east to west, they include 42,900 sq. miles, a larger area than is included in the coal fields of any other state.

Except in the most northern part coal is near at hand and necessarily constitutes the main source of fuel in the production of power. In the last twenty five years the production has increased 519 %, and during the last ten years the increase has been still more rapid. In the year 1905, 38,081,574 tons were mined and a large portion was marketed within the State.

The manufacturing industry in the State is very great and has also a bearing on the use of power. The effect of a "heavy" industry on the utilization of power is quite marked and while Illinois may not have as much as some states, Pennsylvania for example, still the amount of power consumed is comparatively great; Illinois being third in the United States in the capacity of power station equipment. In 1905, 65,840 horse power was recorded, or an increase of 55.1% over that of 1900.

The kinds of power used in Illinois may be included under three heads, viz:

(1) Steam, with auxiliary electric transmission.
(2) Gas Power, and,
(3) Water Power.

Steam Power constituted 75.3% of the total horse power in the State in 1905, and 85.1% in 1900. Electric power as an auxiliary of steam power constituted 19.2% of the total in 1905, and 8.3% in 1900. Gas power is a comparatively new feature of industrial developement, and consequently is still small. In 1905 the total horse power in the State was 12,319 while in 1900 but 8,758 horse power was recorded showing an

increase of nearly 50 per cent. Water power has been very limited owing to the nature of the rivers and their inadaptability for the production of power. However, some water power is available. In 1905, Illinois had 15,030 horse power, and in 1900, 11,614 horse power, showing a very slight increase. From the above it is seen steam power is the principal power of the State, and for our discussion steam power with auxiliary electrical power will be considered principally, altho a gas plant has been available and will also be discussed.

To all consumers and generators of power the hope for a continuance of dividend paying power lies in the possibilities of decreased cost of production. Many things enter into this cost of production which can probably be reduced and which consequently will reduce the cost of power. However, the exact determination of the cost of operating any given power plant is nearly impossible, presenting, as it does, problems that do not admit of mathematical computation. Further, no one plant can be picked out to represent some certain class owing to the particular features of each individual plant and the conditions characteristic of but one plant alone. However, from an analysis of these costs the following heads present themselves as affecting design, location, operation, etc.-

First- First Cost.
Second: Fixed Charges.
Third: Salaries of Officials and Wages.

Fourth: Fuel, Cost, and,

Fifth: Miscellaneous Expenses.

The location of a power plant has a direct bearing on the cost of plant and necessarily on the cost of power. The price of the land on which it stands must be considered; the proximity of the source of fuel supply and the value of this fuel, as steaming fuel, demands attention. Again, location must be considered in regard to output, so as to reduce the transmission costs and losses. Railway and transportation facilities for machinery and fuel shipments, must be included in a desirable location for convenience and adaptation.

In reviewing the power plants in the following sections the cost of power and its relation to location as discussed above, might be better understood by seeing the map with power plants located by black circles and lettered as arranged in summary. A study of these various locations will doubtless give an insight into the important bearing of location on cost of developed power. However, other conditions of operation must also be considered, for at times these might over balance the effect of location.

The object of this thesis, then, is to consider a number of power plants located in various parts of the State, taking into consideration irregularities and peculiarities, and to determine the cost of power. Also, to determine

relation between this cost and various items connected with operation and other power plant costs, and to deduce curves showing these relations.

In order to ascertain the cost of power in Illinois, it was decided that the original sources should be investigated. Instead of collecting and summarizing the results of other investigators, or of working out values from the steam consumption of certain types of engines and the price of coal, it was thought that a direct result might be obtained by appealing directly to the manufacturers of power thruout the State and finding out what their power was costing them.. To this end letters and record sheets were sent out to power plant managers. At first twenty requests were sent and the results from them were so encouraging that fifty more were sent. The companies were selected from the list of the Illinois Manufacturers Association. They were representative in all respects. They manufactured all the various kinds of power and were distributed among all the principal industries of the State. An endeavor was made to distribute the circulars among the steam, water and oil power and between central station and manufacturing plant stations in the same proportions as the total amount of power is divided by Bulletin 52, Census of Manufactures; 1905, Illinois published by the Census Bureau. The returns have, somewhat roughly kept the same proportions. No attempt was made to investigate gas engine and producer power. For

information on that subject the reader is referred to Prof. R. H. Fernnald's report from the United States Geological Survey. As stated before, seventy record sheets were sent out with their accompanying letters. A sample letter and information blank is shown herewith:-

"Urbana, Illinois.
February 4, 1908."

" Dear Sir:-

The enclosed blank is a record sheet of some important statistics on the comparative costs of different kinds of power, being collected by the Mechanical Engineering Department of the University of Illinois. In order to make the compilation as complete and exact as possible it is desired that you fill out this blank and return to the writer.

It is to be strictly understood that no names will be published and no political or commercial use will be made of the knowledge secured.

Thanking you in advance for your kind consideration, I am

Yours very truly

Assistant Professor Steam Engineering
In Charge Mechanical Engineering Laboratory."

RECORD SHEET FOR LAST RECORDED YEAR.

GENERAL DATA

1. Name of Company .... Located at.....
2. Total cost of power plant$ ....
3. Total output of plant, H. P. hrs.........................
   Kw hrs...........................
4. Character of service ....
5. Average length of day run, hours ....
6. Average load factor ....
7. Total salaries of operating officials....................

ENGINE ROOM

1. Kind of units ....Capacity,H.P...
   " " " .... " H.P...
   " " " .... " H.P...
2. Total wages, employes, $.................................
3. Other operating expenses, such as oil, etc...............
4. Miscellaneous expenses not classified ....

BOILER ROOM

1. Boilers ....No..........Total capacity in H.P.
2. Total fuel burned, tons ....
3. Average cost per ton $ ....
4. Total wages, employes $ ....
5. Other operating expenses, oil, waste, etc., $............
6. Water supply-Cost per 1000 gals..........................
7. Exhaust Steam Heating? ....

REMARKS,

It is believed by the authors that the agreement as expressed in the letter has been kept in all particulars. Twenty three companies answered the letter, seventeen of which returned the record sheet more or less completely filled out; five were unable to accede to the request because of lack of data in the proper form, and one returned a point blank refusal. In analyzing the replies it was very evident that few of the companies have good cost-keeping systems. In fact but one company was able to give information such as to show that complete records were kept. Among the items, which it was astonishing to find the companies did not know about, were: the size of plant, cost of plant and load factor. In cases where these items were unknown, a close estimate was made as to the size and cost of plant, and the load factor was worked out from assumed values of the day run and working year. Although this destroyed in a measure, the value of the work, yet it was thought that no large errors were made in the assumptions.

From the returned record sheets the data was tabulated. For all tables the kilowatt, the kilowatt hour and the dollar were the standards of measurement. All calculations were made on the slide rule to three integral figures. Altho most of the stations were heating stations no attempt was made to compute the value of such heating and it was not considered in the cost of power. Station B, was a

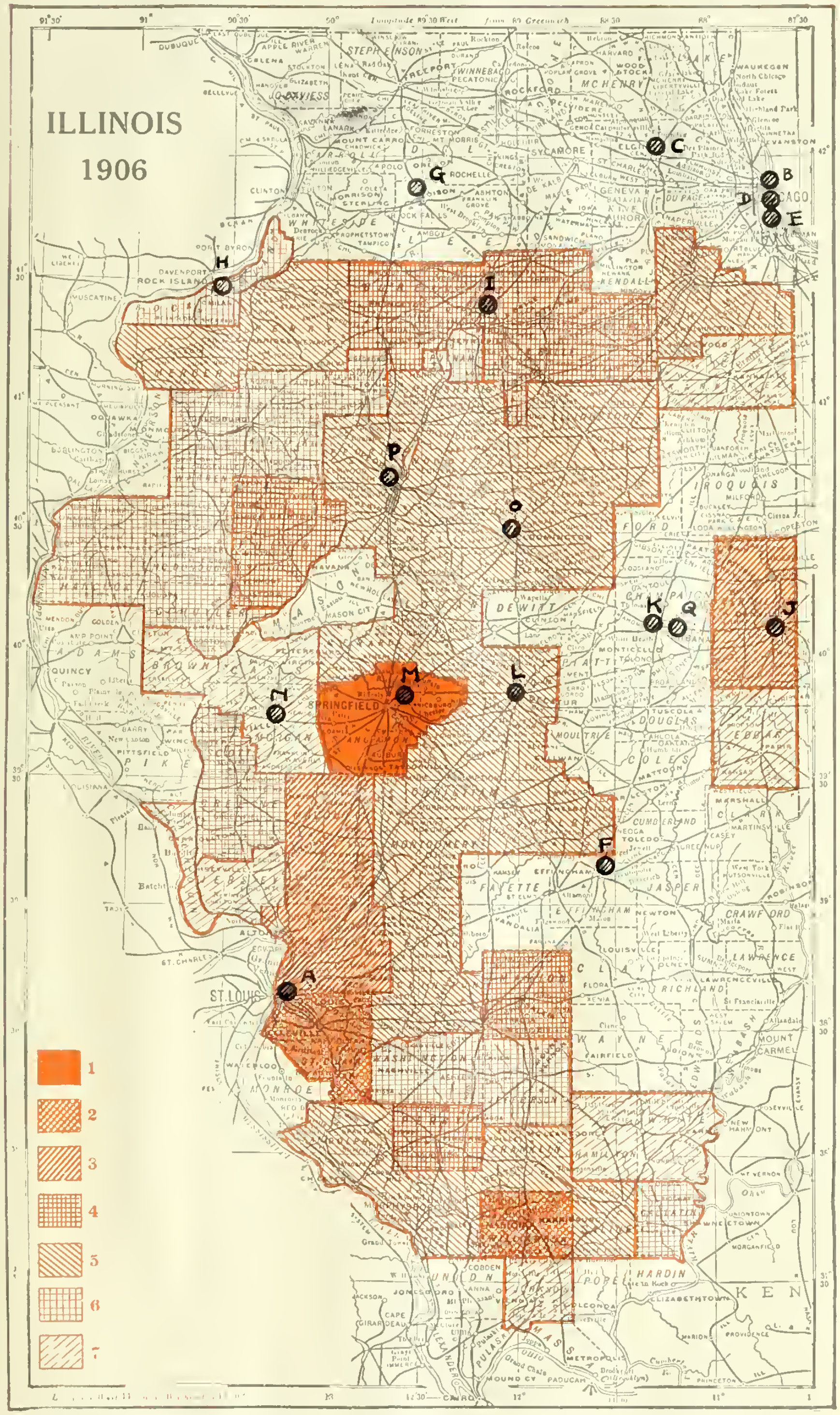
STA'N	MAINTENANCE	FIXED CHAR'S.	REMARKS.
1	11	12	
A	34907	152000	Large, new, central station.
B	5880	–	Central heating plant.
C	582	15600	Manufacturing plant.
D	*12000	71500	" "
E	2450	5500	" "
F	120	3000	New gas plant.
G	428	29200	Hydraulic and Steam.
H	75	3122	Wood & waste Fuel.
I	6600	32600	Constant Load.
J	6151	71500	Central Station.
K	3877	24700	" "
L	3904	27300	" "
M	2937	70250	" "
N	1624	11700	" "
O	2046	28600	" "
P	7070	71500	" "
Q	246	5200	" "

STA'N.	CHARACTER OF SERVICE	SIZE K.W.	OUTPUT K.W.H.	LOAD FACTOR PER CENT	COST OF PLANT DOLLARS.	COST OF POWER	OPR'T'G COST	COST OF FUEL	LABOR COST	MAINTENANCE	FIXED CHAR'S.	REMARKS.
1	2	3	4	5	6	7	8	9	10	11	12	
A	POWER & LIGHT	7400	45,900,000	.85	1168371	194796	159889	103400	41572	34907	152000	Large, new, central station
B	HEATING	-	—	-	-	—	38960	28400	10860	5880	. —	Central heating plant.
C	POWER, LIGHT. HEATING	1385	7780000	.64	* 125000	30862	30280	20470	9702	582	15600	Manufacturing plant.
D	" " "	3680	15200000	47	* 550000	113300	101300	29200	50940	* 12000	71500	" "
E	" " "	538	554100	28.3	42761	16950	14500	10750	3750	2450	5500	" "
F	POWER, LIGHT.	170	447125	30	24000	7120	7000	1500	5280	120	3000	New gas plant
G	" "	WATER 775 STEAM 230	4514000	* 70	234713	7632	7204	4100	3004	428	29200	Hydraulic and Steam.
H	" "	396	1227000	85	25000	8920	8845	2895	5940	75	3122	Wood & waste Fuel.
I	" "	2530	15300000	70	250000	95200	88600	70600	18000	6600	32600	Constant Load.
J	POWER, LIGHT, HEATING	5000	8427124	20	* 550000	77255	71105	48904	15050	6151	71500	Central Station.
K	" " "	1800	5652000	28	* 190000	55630	51760	33083	14800	3877	24700	" "
L	" " "	2100	2747043	15	* 210000	38799	34895	17161	3830	3904	27300	" "
M	POWER	4000	13761000	39.5	* 540000	63993	61056	38420	19699	2937	70250	" "
N	POWER, LIGHT.	900	1241159	16	* 90000	20193	18566	12139	4803	1624	11700	" "
O	POWER, LIGHT, HEATING	2000	4869490	28	* 220000	65455	63400	44490	16864	2046	28600	" "
P	POWER.	4000	12350000	35.5	* 550000	53000	45800	30025	8805	7070	71500	" "
Q	POWER. LIGHT. HEATING	375	448405	17	* 40000	11350	11103	4956	5901	246	5200	" "
	Note: * Assumed Values.											

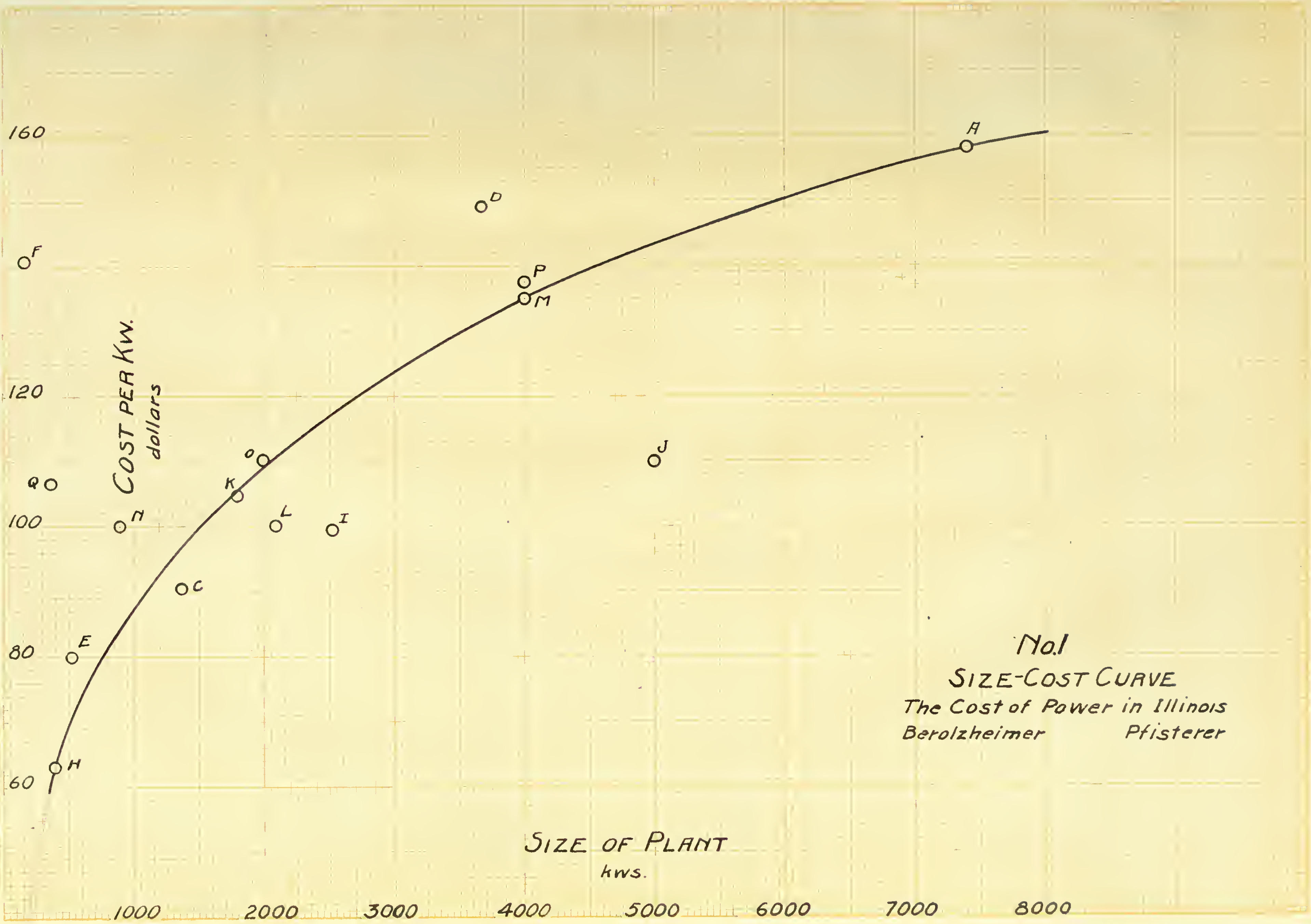
purely heating station and shows the modern practice of central station power and cemtral block station heating. The load factor was expressed in per cent and considered as the ratio of the total yearly kilowatt hour output to the product of the size of the plant, the length of day run and the working year. For table No. III, interest was assumed at 5 % of the total cost of the station, insurance and taxes, 2 %, and depreciation at 6.5 or 7 %, depending on the type of station. Maintenance was taken from Table No. 2.

The distribution of the stations is shown by the map on following pages.

Following this will be found the table giving the costs as derived from data obtained from correspondence. A close reading of this will give a good insight into the nature and kind of plant, which might prove helpful in studying the succeeding curves and tables.



Map showing relative intensity of coal production by counties. (1) Over 4,000,000 short tons; (2) 3,000,000 to 4,000,000; (3) 2,000,000 to 3,000,000; (4) 1,000,000 to 2,000,000; (5) 100,000 to 1,000,000; (6) 10,000 to 100,000; (7) Under 10,000.

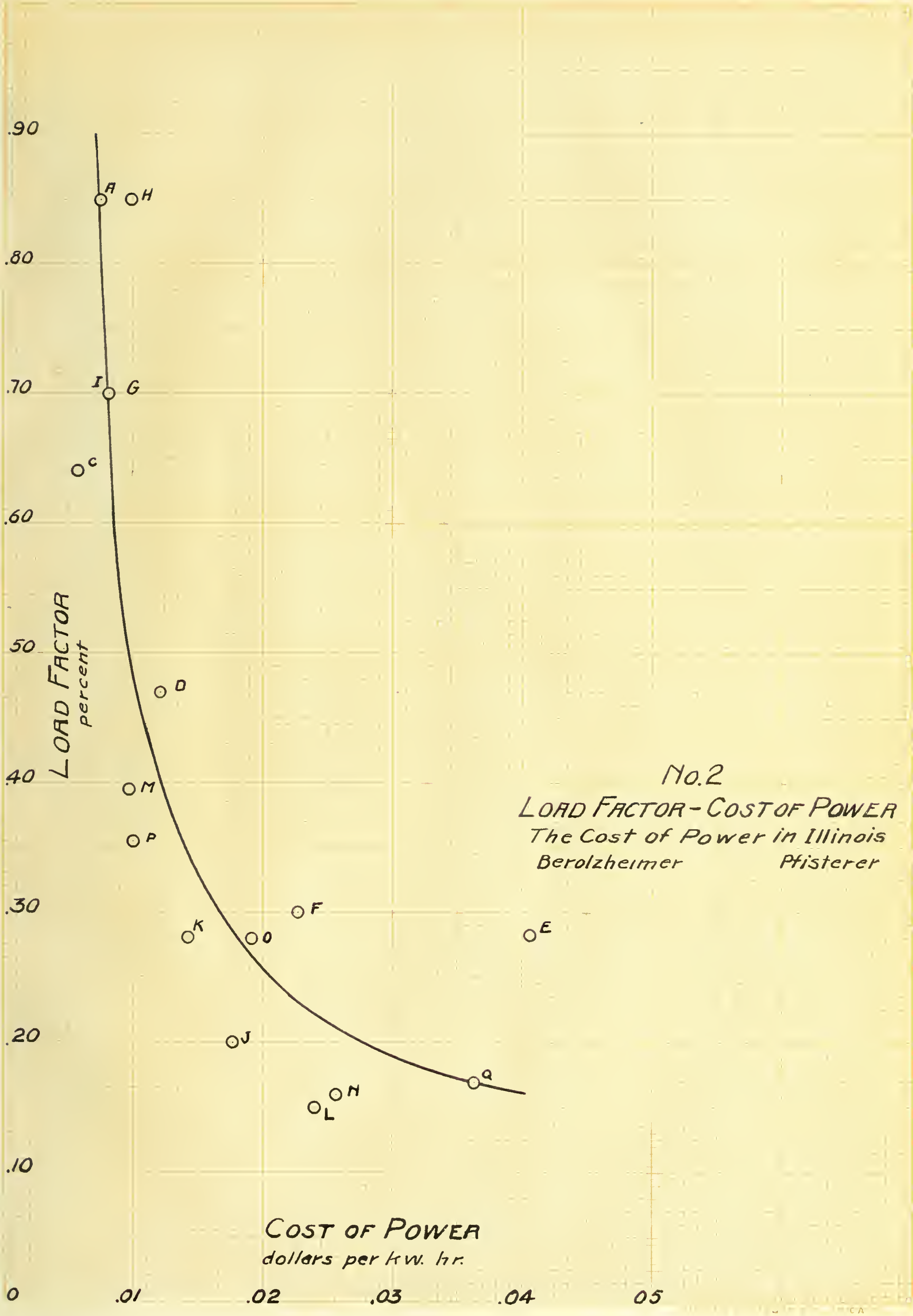


No.1

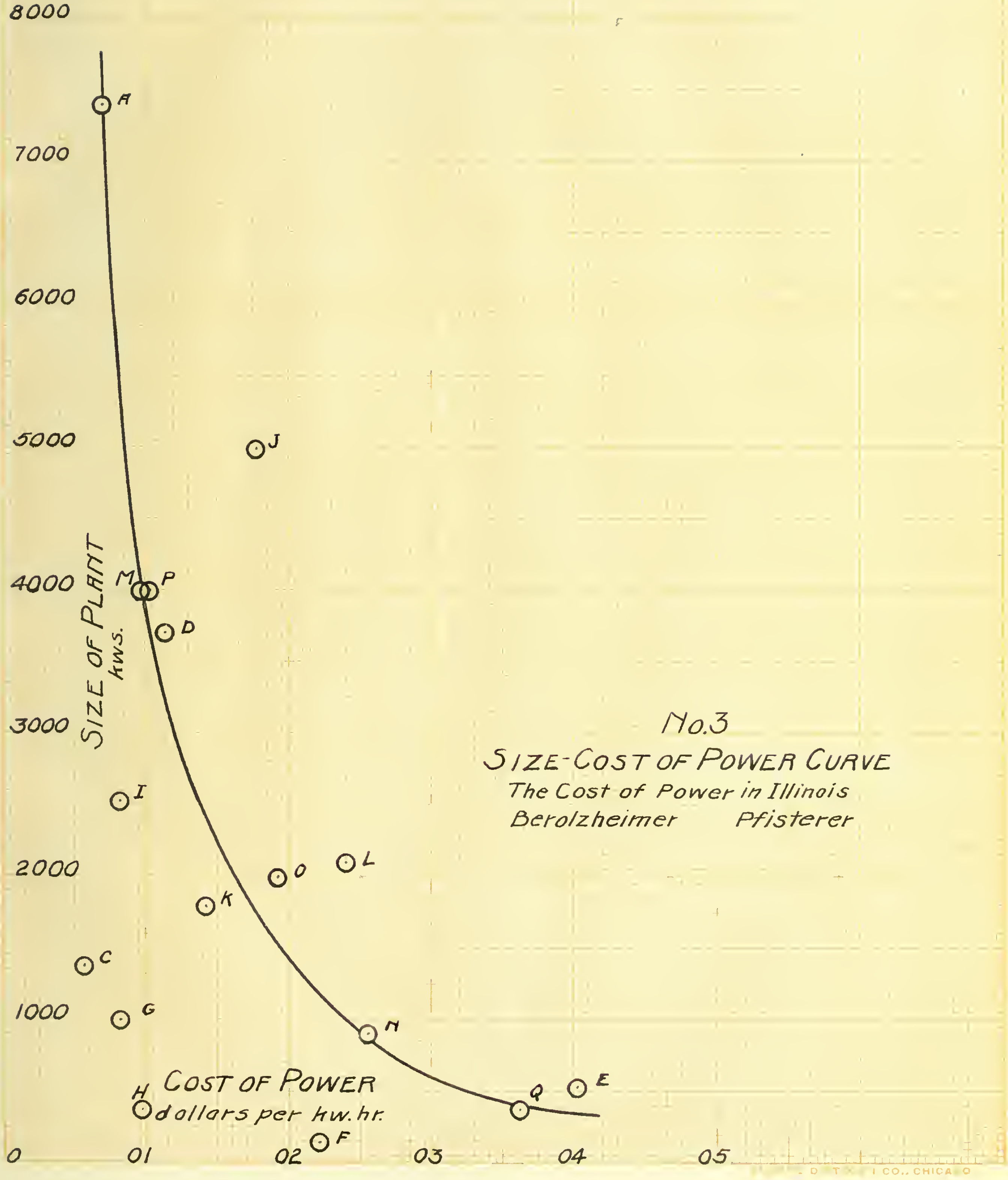
SIZE-COST CURVE

The Cost of Power in Illinois

Berolzheimer Pfisterer



No. 2
LOAD FACTOR - COST OF POWER
The Cost of Power in Illinois
Berolzheimer Pfisterer

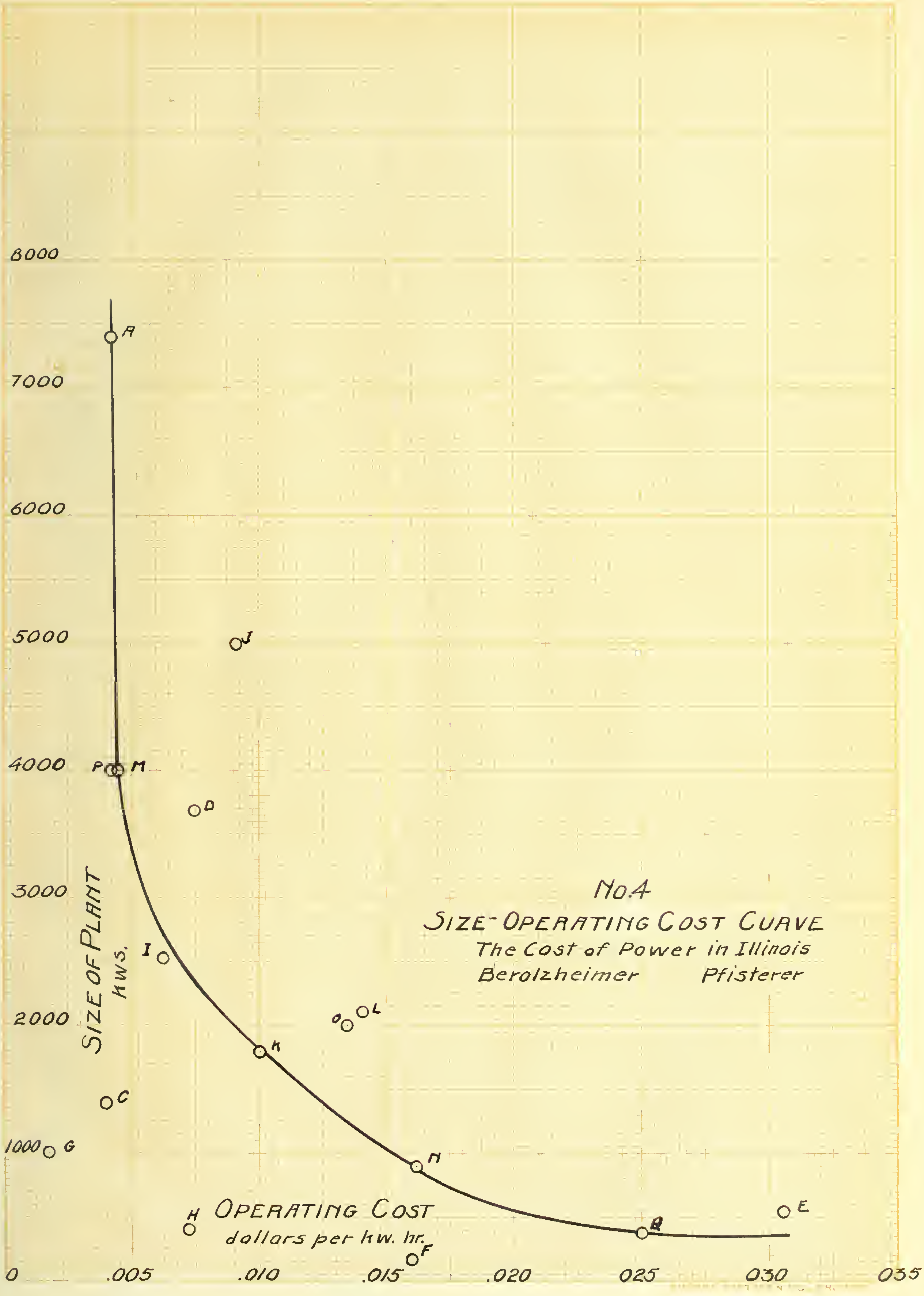


No.3

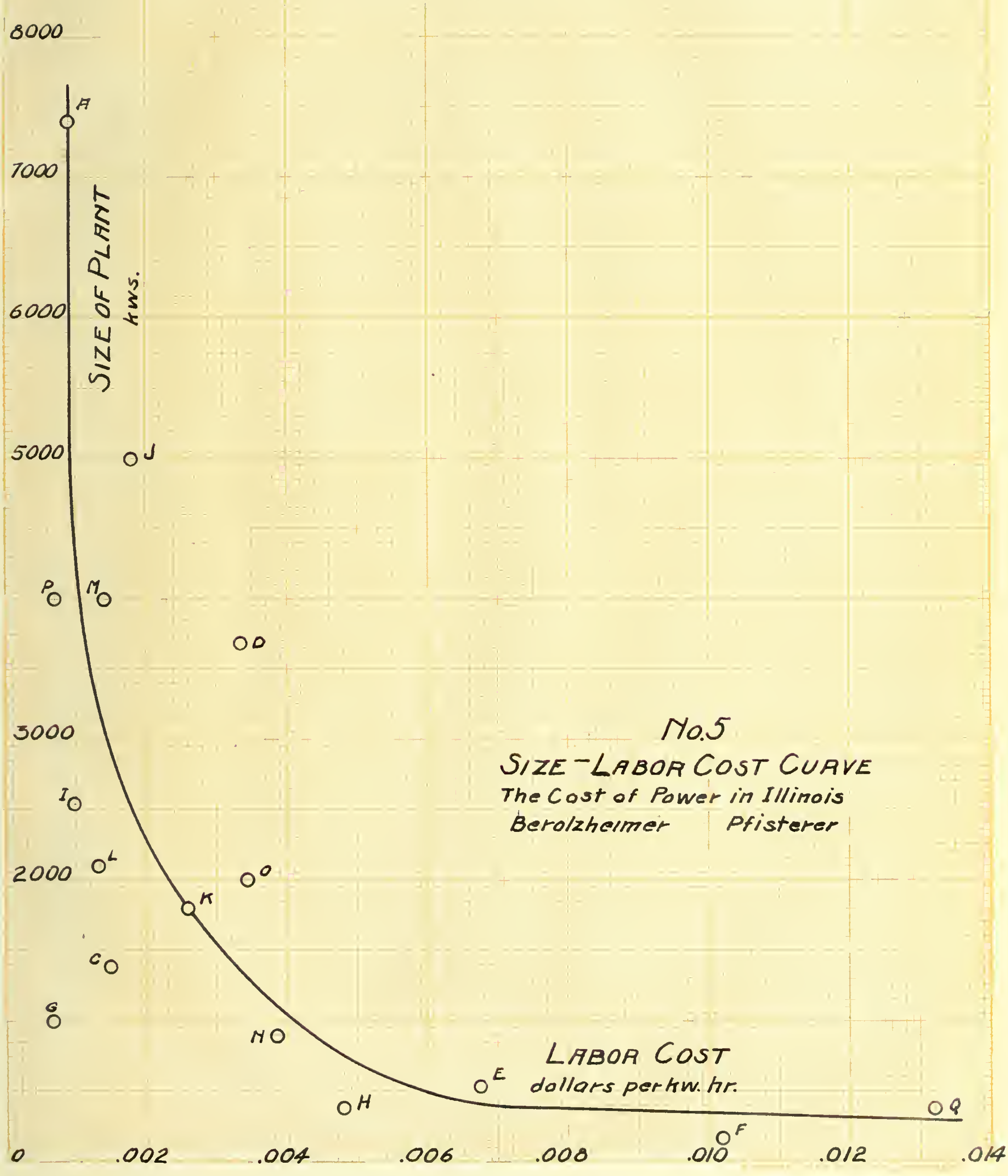
SIZE-COST OF POWER CURVE

The Cost of Power in Illinois

Berolzheimer Pfisterer



No.4
SIZE-OPERATING COST CURVE
The Cost of Power in Illinois
Berolzheimer Pfisterer


No. 5
SIZE-LABOR COST CURVE
The Cost of Power in Illinois
Berolzheimer
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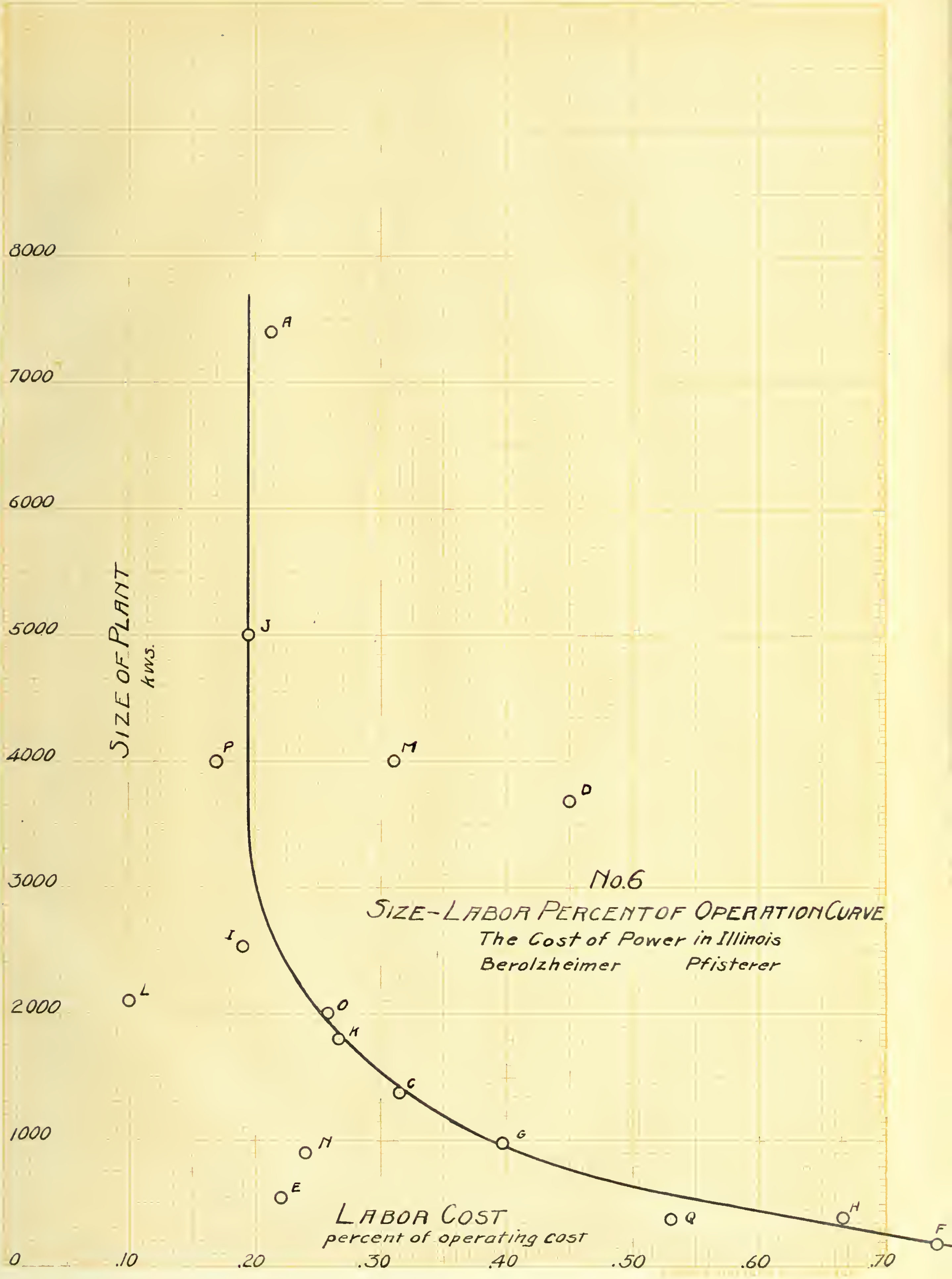
SIZE OF PLANT
kws.
LABOR COST
dollars per kw. hr.
8000
7000
6000
5000
3000
2000
0
.002
.004
.006
.008
.010
.012
.014
A
J
P
M
D
I
L
O
K
C
G
N
E
H
Q
F

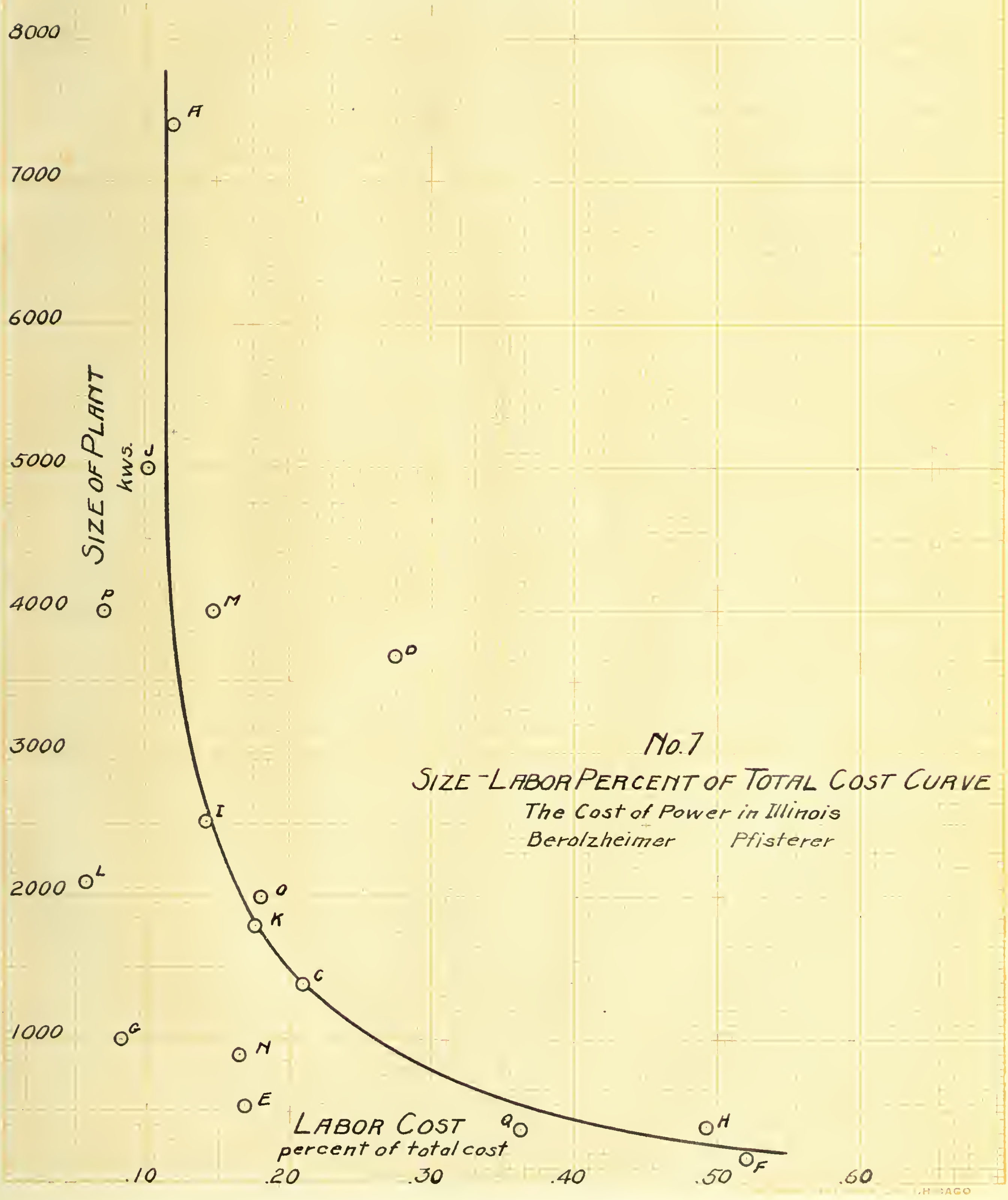


No.6

SIZE-LABOR PERCENT OF OPERATION CURVE

The Cost of Power in Illinois

Berolzheimer Pfisterer

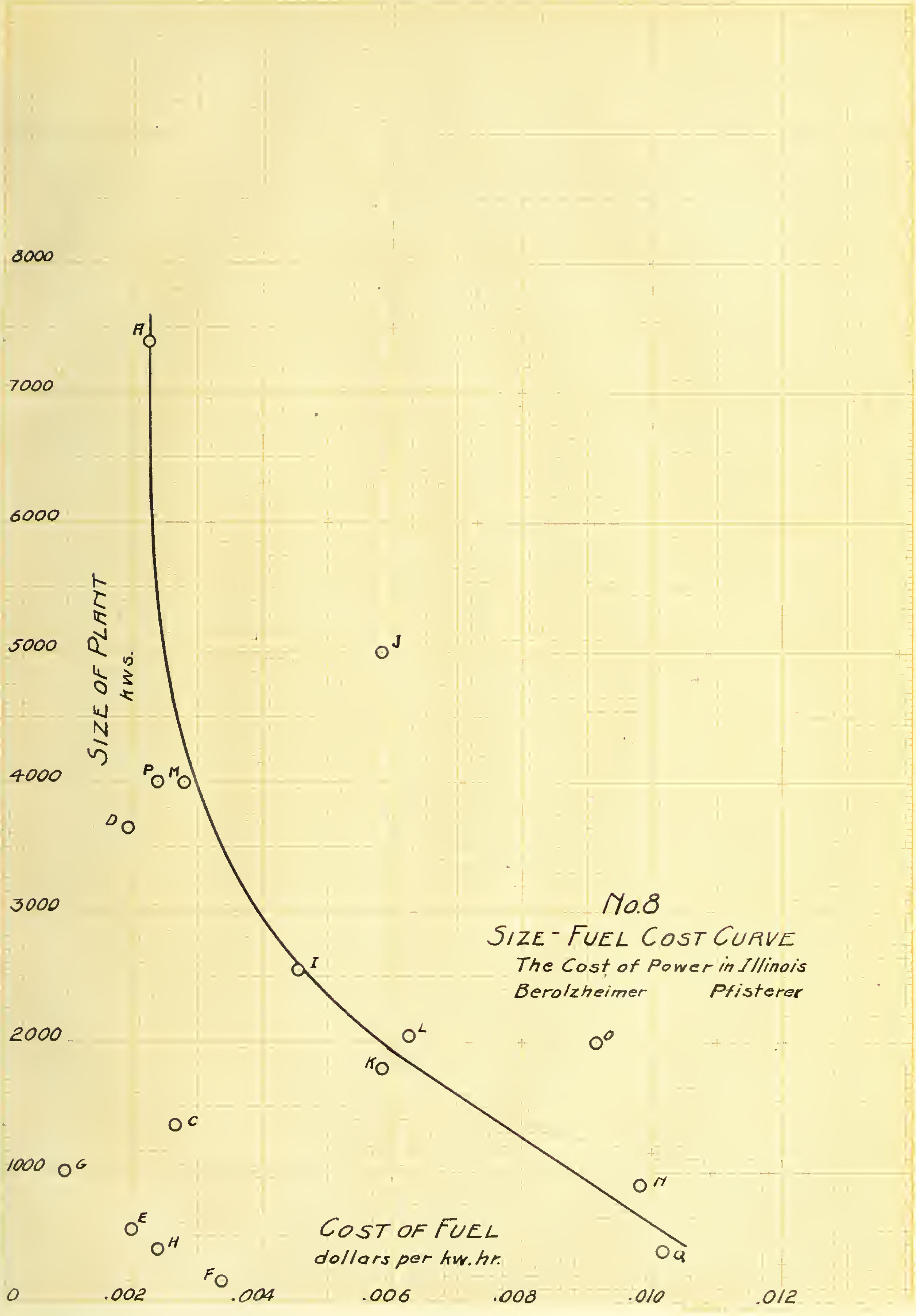


No. 7

SIZE - LABOR PERCENT OF TOTAL COST CURVE

The Cost of Power in Illinois

Berolzheimer Pfisterer

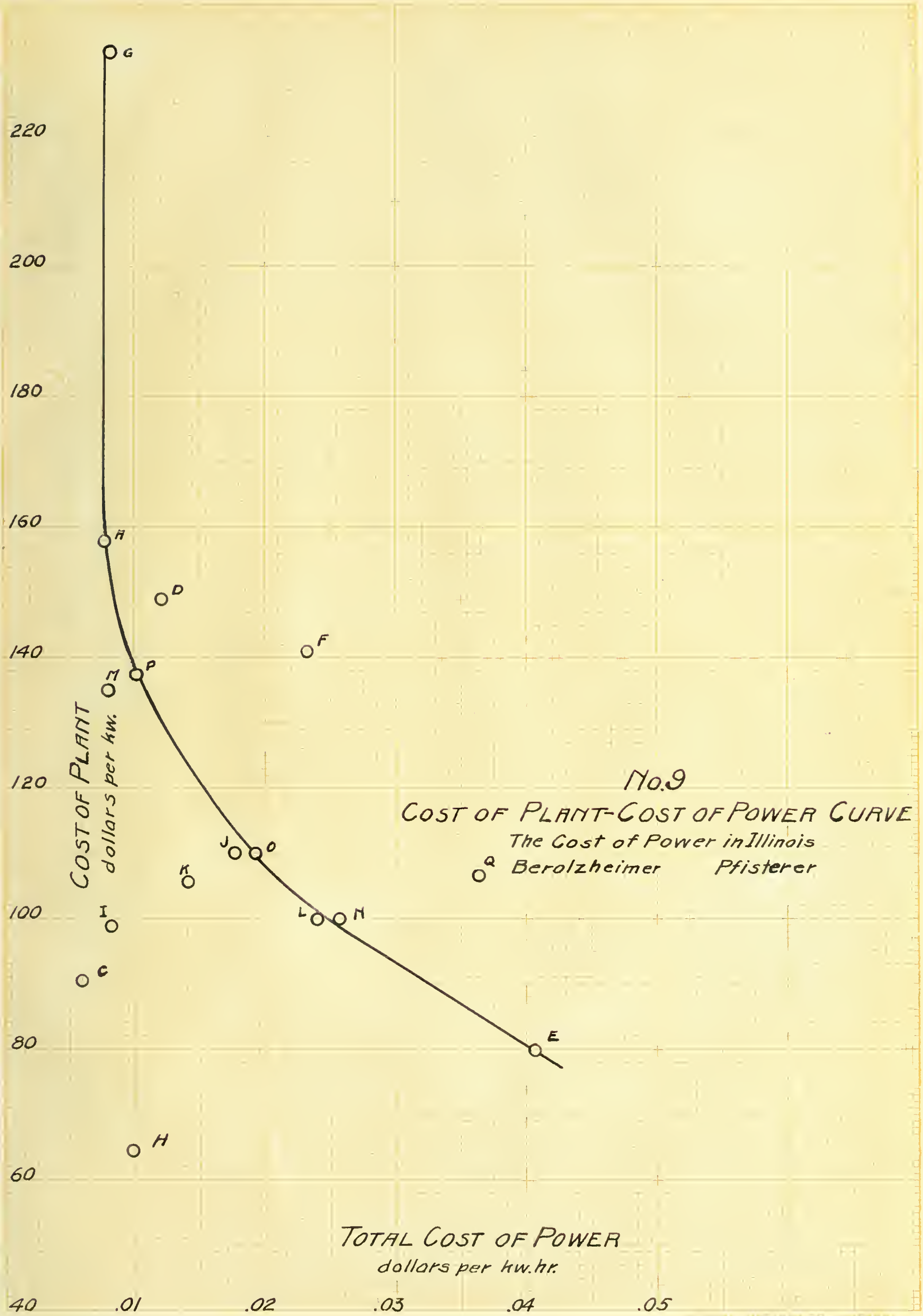


No. 8

SIZE - FUEL COST CURVE

The Cost of Power in Illinois

Berolzheimer Pfisterer

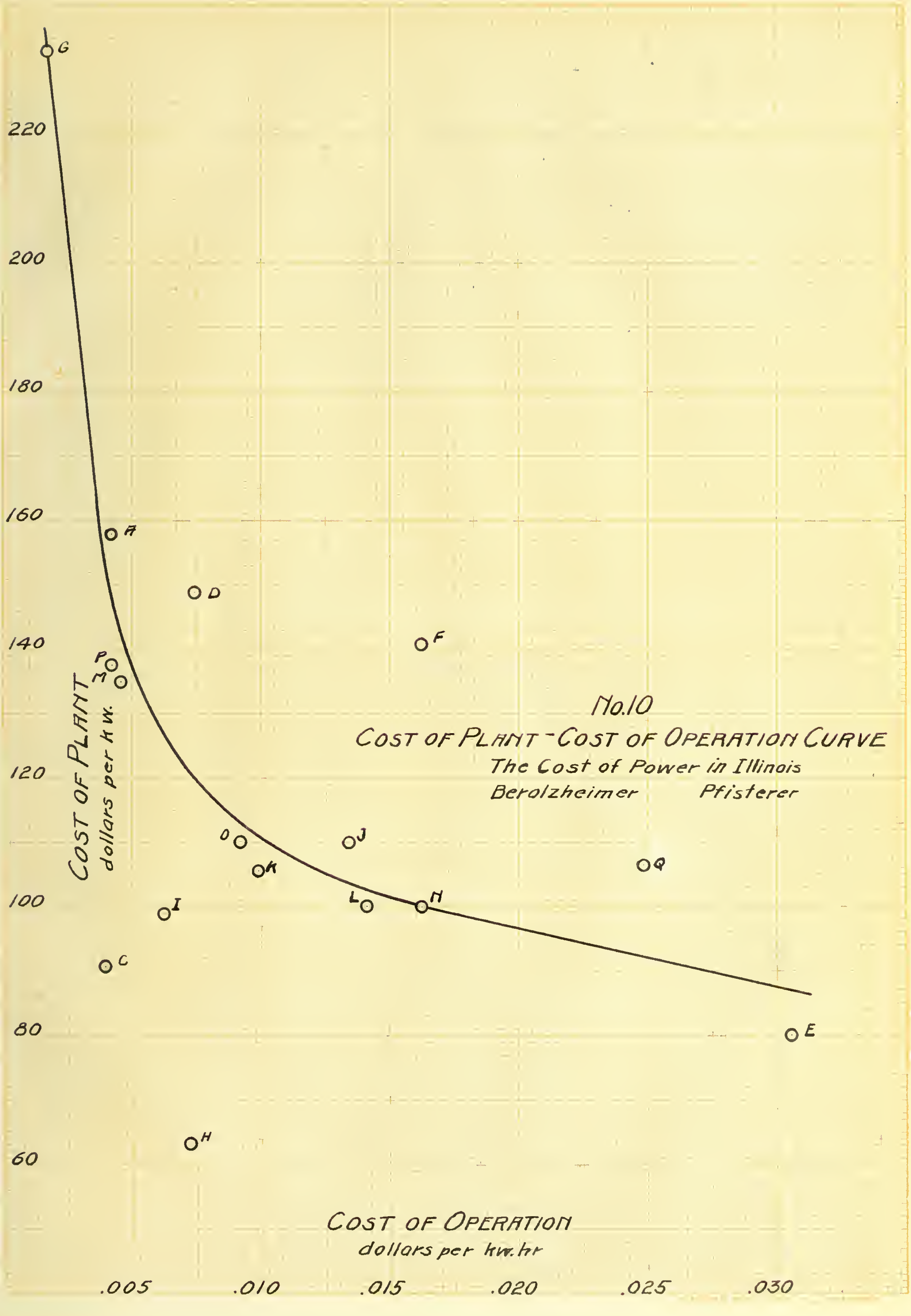


No. 9

COST OF PLANT-COST OF POWER CURVE

The Cost of Power in Illinois

Berolzheimer Pfisterer

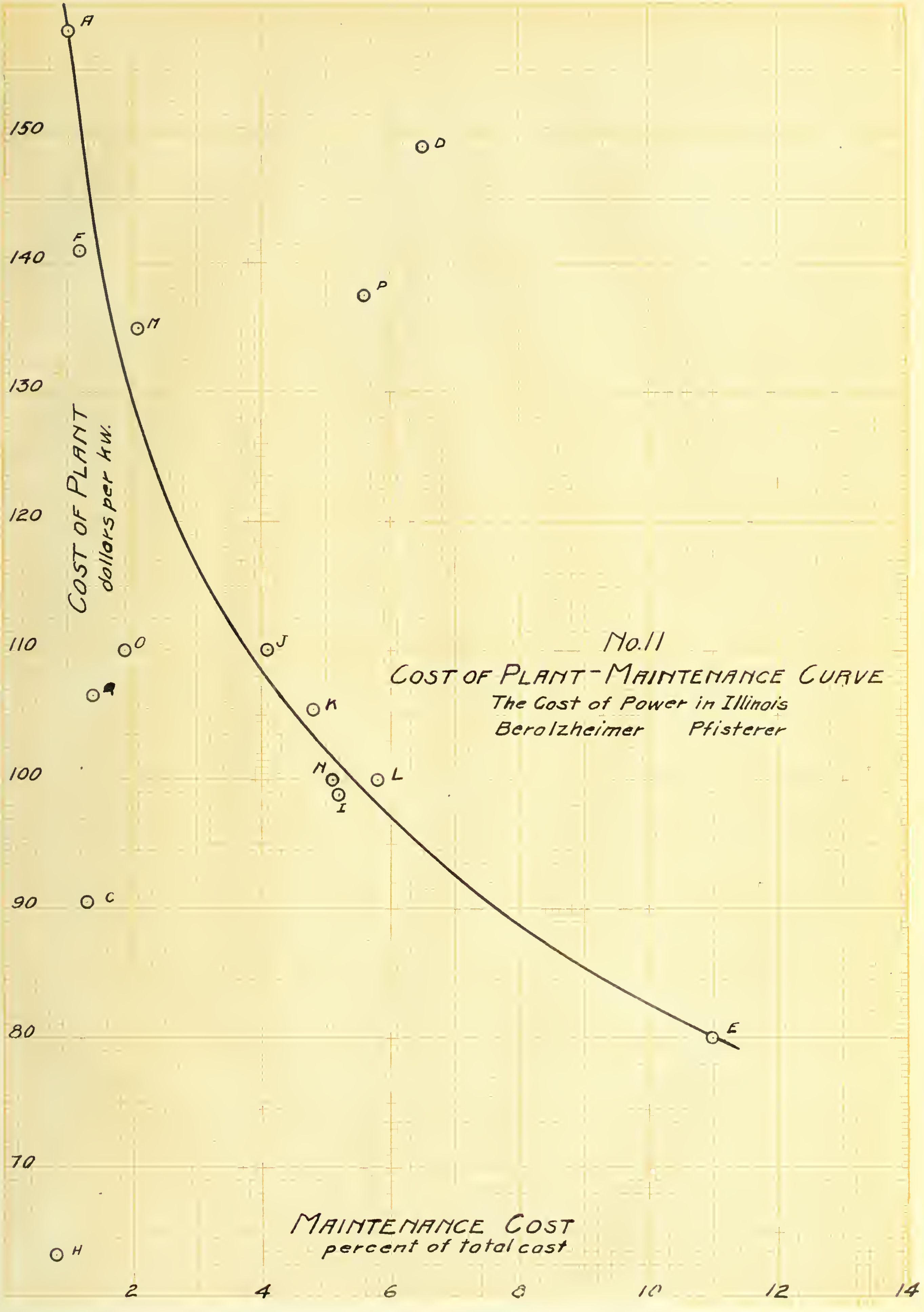


No.10

Cost of Plant - Cost of Operation Curve

The Cost of Power in Illinois

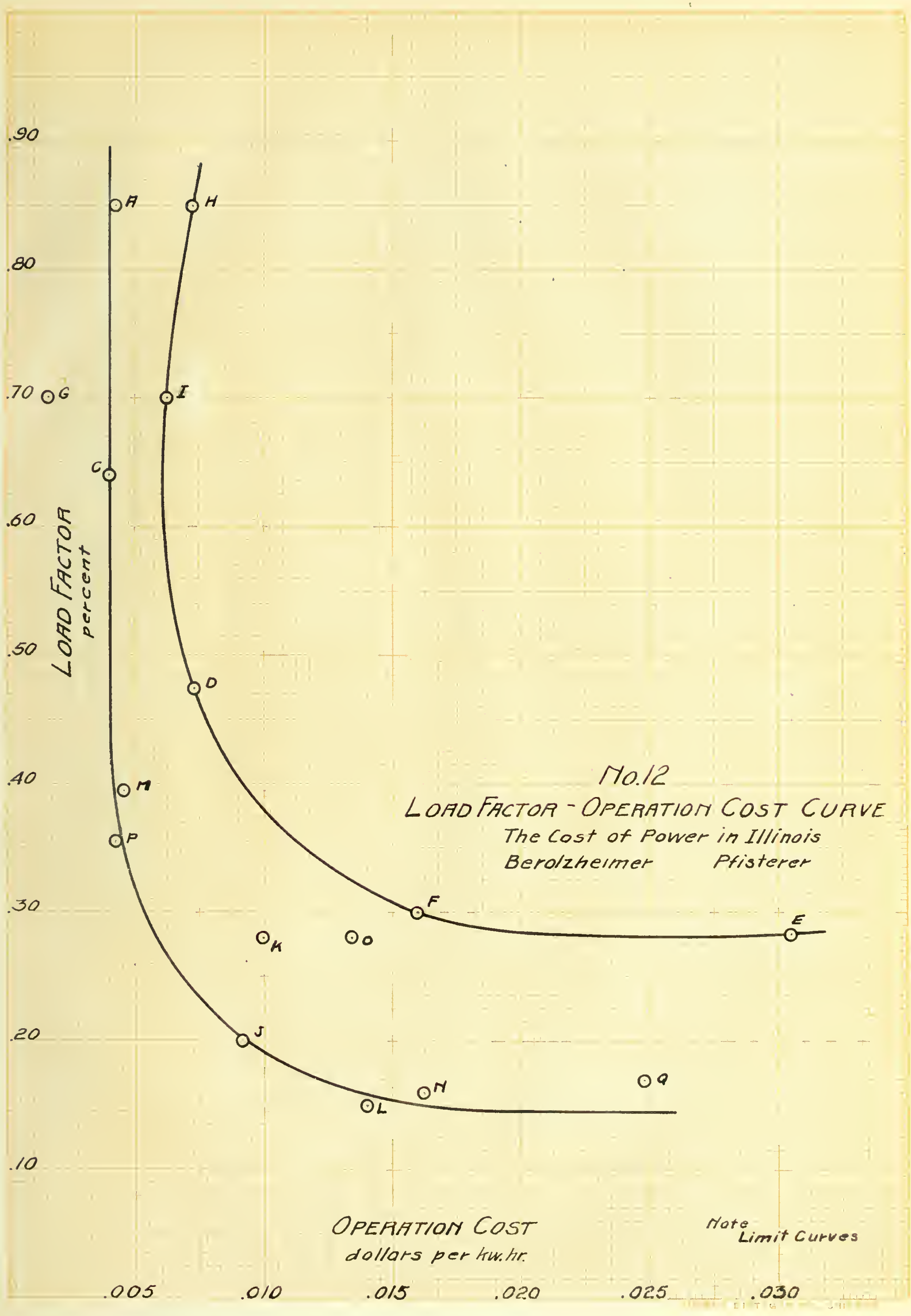
Berolzheimer Pfisterer


No.11

COST OF PLANT-MAINTENANCE CURVE

The Cost of Power in Illinois

Berolzheimer Pfisterer

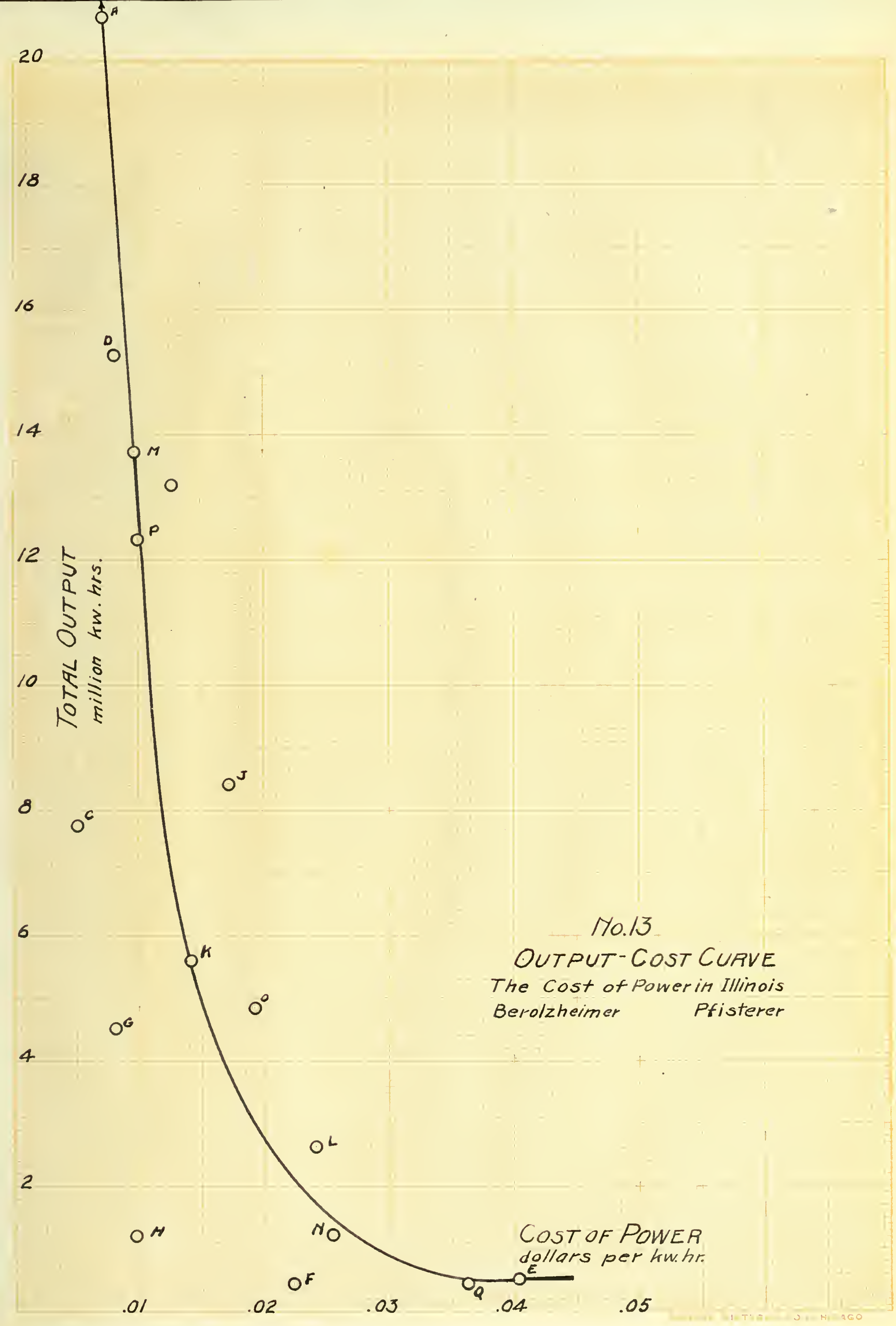


No.12

LOAD FACTOR - OPERATION COST CURVE

The Cost of Power in Illinois

Berolzheimer Pfisterer

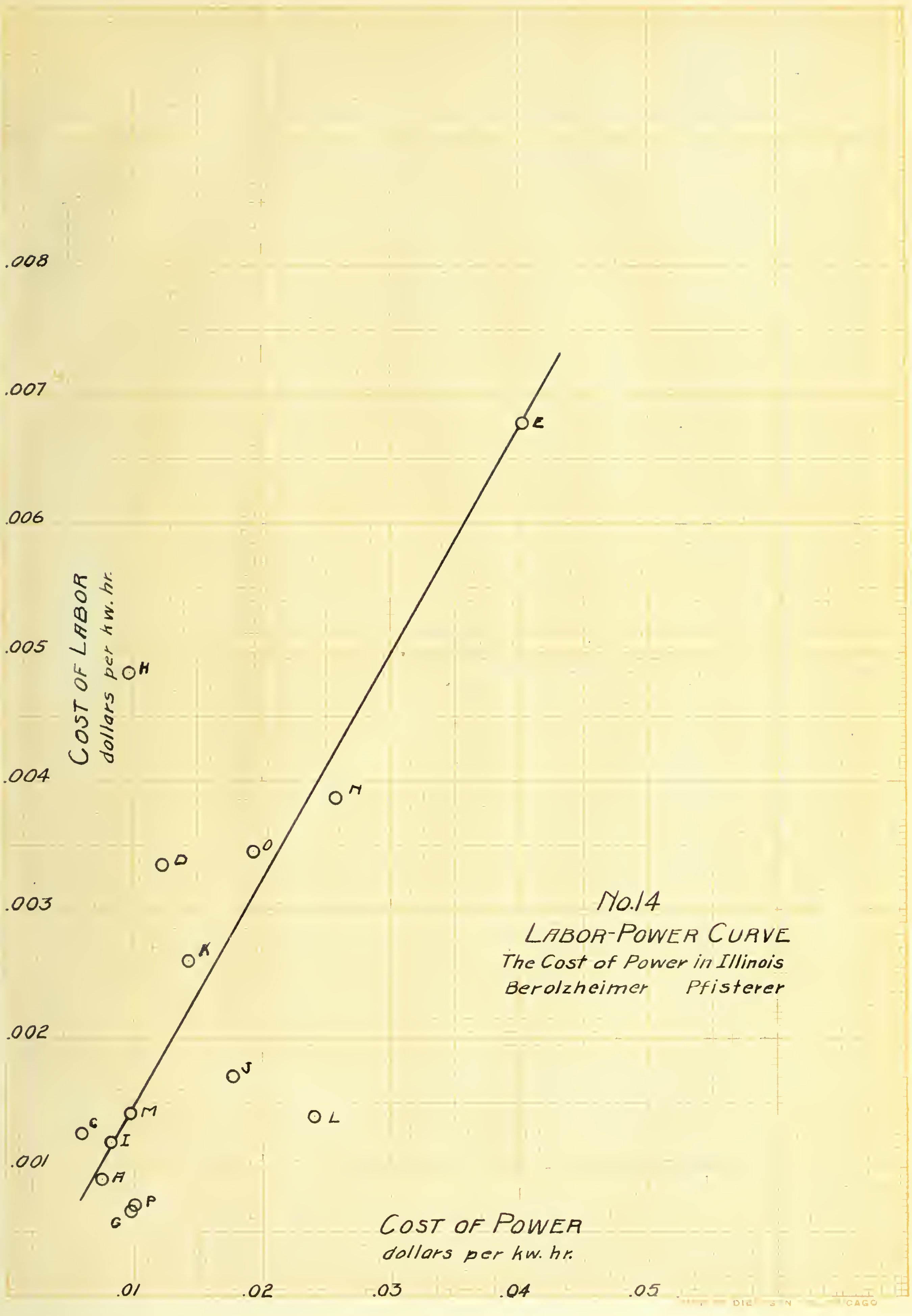


No. 13

OUTPUT-COST CURVE

The Cost of Power in Illinois

Berolzheimer Pfisterer



No.14

LABOR-POWER CURVE

The Cost of Power in Illinois

Berolzheimer Pfisterer

STATION	COST OF PLAN PER K.W.	% OF 31	MISCELLANEOUS PER K.W.H.	% OF 24	% OF 31	COST OF POWER PER K.W.H.
13	14 $	27	28 ¢	29	30	31 ¢
A	158.00	43.8	.0325	7.6	4.3	.7550
C	* 90.50	33.6	–	–	–	.5980
D	* 149.50	38.6	.1390	18.7	11.4	1.216
E	80.00	24.8	–	–	–	4.060
F	141.00	29.6	.0590	3.7	2.6	2.269
G	233.00	79.4	.0020	0.1	0.03	.8190
H	63.25	26.0	–	–	–	.9820
I	98.75	25.0	–	–	–	.8280
J	* 110.00	48.2	.0830	9.1	4.7	1.766
K	* 105.50	30.8	.0707	7.2	5.0	1.420
L	* 100.00	41.4	.5100	2.6	1.5	2.404
M	* 135.00	52.5	.0220	4.6	2.3	.9700
N	* 100.00	36.9	.1310	8.1	4.9	2.564
O	* 110.00	30.4	.0420	3.6	2.2	1.927
P	* 137.50	57.5	.0580	0.14	0.6	1.006
Q	* 106.50	31.8	.0560	2.3	1.5	3.640

Note:

* Assum

∞ Includ

STATON	COST OF PLANT PER K.W	COST OF LABOR PER K.W.H.	% OF 24	% OF 31	FUEL COST PER K.W.H	% OF 24	% OF 31	MAINTENANCE PER K.W.H.	% OF 24	% OF 31	OPERATION COST PER K.W.H.	% OF 31	FIXED CHARGES PER K.W.H.	% OF 31	MISCELLANE'US PER K.W.H.	% OF 24	% OF 31	COST OF POWER PER K.W.H.
13	14 $	15 ¢	16	17	18 ¢	19	20	21 ¢	22	23	24 ¢	25	26 ¢	27	28 ¢	29	30	31 ¢
A	158.00	.0907	21.4	12.0	.2250	53.0	32.0	.0760	17.9	1.0	.4240	56.2	.3310	43.8	.0325	7.6	4.3	.7550
C	*90.50	.1250	31.5	21.0	.2640	66.5	44.0	.0075	1.9	1.3	.3970	66.2	.2010	33.6	–	–	–	.5980
D	*149.50	.3350	45.0	27.6	.1920	25.7	16.0	.0790	10.6	6.5	.7460	61.5	.4700	38.6	.1390	18.7	11.4	1.216
E	80.00	.6770	22.1	16.8	1.950	63.7	48.0	.4420	14.5	11.0	3.060	75.4	1.000	24.8	–	–	–	4.060
F	141.00	1.180	74.0	52.0	.3360	21.0	15.0	.0268	1.7	1.2	1.597	70.4	.6720	29.6	.0590	3.7	2.6	2.269
G	233.00	.0670	39.6	8.2	.0910	53.8	11.0	.0095	5.6	1.2	.1690	20.6	.6500	79.4	.0020	0.1	0.03	.8190
H	63.25	.4840	66.6	49.2	.2360	32.5	24.0	.0062	0.8	0.6	.7260	74.0	.2560	26.0	–	–	–	.9820
I	98.75	.1180	19.0	14.3	.4560	73.3	55.4	.0430	6.9	5.2	.6220	75.0	.2060	25.0	–	–	–	.8280
J	*110.00	.1790	19.6	10.2	.5810	63.4	33.0	.0730	8.0	4.1	∞.9160	50.4	.8500	48.2	.0830	9.1	4.7	1.766
K	*105.50	.2620	26.6	17.7	.5850	59.0	41.2	.0680	6.9	4.8	∞.9840	69.2	.4360	30.8	.0707	7.2	5.0	1.420
L	*100.00	.1395	9.9	5.8	.6240	44.2	26.0	.1400	10.0	5.8	∞1.410	58.6	.9940	41.4	.5100	2.6	1.5	2.404
M	*135.00	.1430	31.0	14.8	.2790	60.7	28.8	.0200	4.4	2.1	∞.4600	47.5	.5100	52.5	.0220	4.6	2.3	.9700
N	*100.00	.3870	24.0	15.0	.980	60.5	38.2	.1300	8.0	5.1	∞1.620	63.1	.9440	36.9	.1310	8.1	4.9	2.564
O	*110.00	.3460	25.8	18.0	.9130	68.0	47.4	.0400	2.8	1.9	∞1.340	69.6	.5870	30.4	.0420	3.6	2.2	1.927
P	*137.50	.0713	16.8	7.1	.243	57.0	24.0	.0570	13.5	5.6	∞.4270	42.5	.5790	57.5	.0580	0:1.4	0.6	1.006
Q	*106.50	1.320	53.0	36.3	1.110	44.7	30.5	.0500	2.0	1.4	∞2.480	68.2	1.160	31.8	.0560	2.3	1.5	3.640

Note:
* Assumed Values.
∞ Includes Maintenance.

STATION	DEPRECIATION PER K.W.H. 32 ¢	INSURANCE PER K.W.H. 33 ¢	IN PE
A	.1520	.0520	.
C	.0880	.0320	.
D	.2170	.0720	.
E	.4600	.1540	.
F	.2940	.1080	.
G	.2860	.1040	.
H	.1140	.0400	.
I	.0920	.0320	.
J	.3940	.1300	.
K	.2000	.0680	.
L	.4590	.1530	.
M	.2350	.0790	.
N	.4370	.1450	.
O	.3720	.0900	.
P	.2670	.0890	.
Q	.5360	.1780	.

STATION	DEPRECIATION PER K.W.H.	INSURANCE PER K.W.H.	INTEREST PER K.W.H.	MAINTENANCE PER K.W.H.	% OF 37	TOTAL FIXED CHAR'S.	
	32 ¢	33 ¢	34 ¢	35 ¢	36 %	37 ¢	
A	.1520	.0520	.1270	.0760	2.9	.4070	
C	.0880	.0320	.0810	.0075	.47	.2085	
D	.2170	.0720	.1810	.0790	2.2	.5490	
E	.4600	.1540	.3860	.4420	5.7	1.442	
F	.2940	.1080	.2700	.0268	.50	.6988	
G	.2860	.1040	.2600	.0425	.80	.6925	
H	.1140	.0400	.1020	.0061	.30	.2622	
I	.0920	.0320	.0820	.1180	7.4	.3310	
J	.3940	.1300	.3260	.0730	1.1	.9750	
K	.2000	.0680	.1680	.0680	2.0	.5040	
L	.4590	.1530	.3820	.1400	1.8	1.134	
M	.2350	.0790	.1960	.0200	.50	.5300	
N	.4370	.1450	.3620	.1300	1.8	1.074	
O	.3720	.0900	.2250	.0400	.90	.6270	
P	.2670	.0890	.2230	.0570	1.3	.6360	
Q	.5360	.1780	.4460	.0500	.55	1.210	

The conclusions are shown mainly by the curves, and they will be discussed first.

Curve No. 1 shows that the larger stations considered cost more per Kilowatt than smaller ones, chiefly because they are better stations. 2

Curve No. 2 shows that increasing the load factor greatly decreases the cost of power per kw hr.

Curve No. 3 shows that larger stations make power cheaper than smaller ones.

Curve No. 4 shows that the operating cost per kw hr. is much less in large stations than in smaller ones.

Curve No. 5 shows that the cost of labor per kw hr. is less for large stations than for small ones.

Curve No. 6 shows that the ratio in per cent of the labor cost per kw hr. to the operating cost per kw hr. is much larger in small stations than in larger ones.

Curve No. 7 shows that the labor cost per kw hr. is a smaller per cent of the total cost per kw hr. for large stations than for small ones.

Curve No. 8 shows that the cost of fuel per kw hr. decreases as the size of plant increases.

Curve No. 9 shows that the higher priced plants make power cheaper than low priced plants.

Curve No. 10 shows that the cost of operation per kw hr. decreases rapidly as the cost of the station per kw increases.

Curve No. 11 shows that the per cent that the maintenance cost is of the total cost, decreases as the unit cost of the station increases.

Curve No. 12 shows that as the load factor increases,the operating cost per kw hr. decreases very rapidly.

Curve No. 13 shows that as the total output increases, the cost of power per kw hr. decreases slightly.

Curve No. 14 shows that as the labor cost per kw hr. increases, the total cost per kw hr. increases in direct ratio. Other conclusions are as follows:-

As a general average operating expenses are about 60% and fixed charges 40% of the total cost.

Fuel is the largest item of operation expenses, amounting in general to 60 %, while labor amounts to 33 % , and maintenance and miscellaneous to 7 %.

The usual assumption of 2 % for maintenance is about right since the general average of our sixteen plants was 1.89 %.

Water power is, generally speaking, the cheapest power, despite the high first cost and fixed charges.

It cheapens power decidedly when waste products, such as refuse from wood-working factories are used for fuel.

The miscellaneous charges should not run above 5 % of the total cost of power under ordinary conditions.

Power can be made in Illinois for .75¢ per kw and in no cases should cost more than 2.5¢ per kw.

While from the very nature of the problem and the diversity of kind of plants investigated, the results of this

thesis are not comparable, yet the authors believe that the conclusions reached are in all cases quite true and justifiable.

From the above it will be seen, the cost of manufactured power in the State of Illinois is a variable quantity. Many conditions throughout the State affect this cost to a great degree, and the prudent manufacturer will well consider some of the points herein mentioned, before final selection and definite location are decided upon.

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